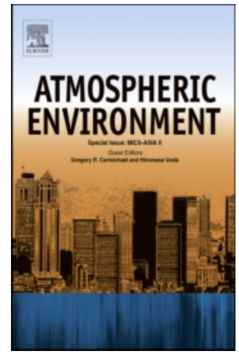

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PII: S1352-2310(08)00531-1
DOI: 10.1016/j.atmosenv.2008.05.051
Reference: AEA 8368

To appear in: *Atmospheric Environment*

Received Date: 20 November 2007
Revised Date: 9 May 2008
Accepted Date: 20 May 2008

Please cite this article as: Baldauf, R., Thoma, E., Khlystov, A., Isakov, V., Bowker, G., Long, T., Snow, R. Impacts of Noise Barriers on Near-Road Air Quality, Atmospheric Environment (2008), doi: 10.1016/j.atmosenv.2008.05.051

Impacts of Noise Barriers on Near-Road Air Quality

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ABSTRACT

Numerous health studies conducted worldwide suggest an increase in the occurrence of adverse health effects for populations living, working, or going to school near large roadways. A study was designed to assess traffic emission impacts on air quality near a heavily traveled highway. The portion of highway studied included a section of open field and a section with a noise barrier adjacent to the road. In addition, the section containing the noise barrier included a portion with vegetation in the vicinity of the barrier. Thus, this field study provided an opportunity to evaluate near road air quality with no barriers, with a noise barrier only, and with a noise barrier and vegetation adjacent to the road. Pollutants measured under these scenarios included carbon monoxide (CO) and particulate matter (PM).

Measurements showed the effects of a noise barrier on near road air quality. The presence of this structure often led to pollutant concentration reductions behind the barrier during meteorological conditions with winds directionally from the road. CO and PM number concentrations generally decreased between 15 and 50 percent behind the barrier. However, conditions occurred when

pollutant concentrations were greater behind the barrier than when no barrier was present. These results imply that the presence of a noise barrier can lead to higher pollutant concentrations on the road during certain wind conditions. In addition, the study results suggested that the presence of mature trees in addition to the barrier further lowered PM number concentrations.

Keywords

Motor vehicle emissions, noise barriers, near-road, particulate matter, carbon monoxide

INTRODUCTION

Interest in how roadside structures such as noise barriers and vegetation affect the concentrations of motor vehicle emitted pollutants in the near road microenvironment has increased because many recent epidemiological studies have reported associations between a population's proximity to high traffic volume roadways and adverse health effects (see references in Baldauf et al., 2008). These physical barriers may affect pollutant concentrations around the structure by blocking initial dispersion, and increasing turbulence and initial mixing of the emitted pollutants (Tan and Lepp, 1977; Madders and Lawrence, 1985; Lidman, 1985; Swamy and Lokesh, 1993; Höelscher et al., 1993).

Noise barriers reduce noise levels from traffic by blocking and deflecting sound waves. These barriers may also affect air pollutant dispersion, leading to increased vertical mixing due to the upward deflection of air flow caused by the structure. Studies suggest that this upward deflection of air may create a recirculation cavity downwind of the barrier, extending from 3 to 12 wall heights downwind, containing a well-mixed, and often lower, zone of pollution concentrations (Nokes and Benson, 1984; Paul-Carpenter and Barboza 1988; Hölscher et al., 1993; Swamy and Lokesh, 1993). Noise barriers adjacent to a roadway may also inhibit lateral air movements off the road, leading to elevated on-road pollutant concentrations (Tan and Lepp, 1977; Lidman, 1985; Nokes and Benson, 1984). Modeling by Bowker et al. (2007) also demonstrated a potential for the vertical uplift of air flow over the barrier and the possibility of plume reattachment further downwind of the recirculation zone. This situation could result in higher pollutant concentrations behind the barrier at further distances than for equivalent distances with no barrier present.

Studies also suggest that vegetation stands affect downwind pollutant concentrations. Modeling by Bowker et al. (2007) indicated that the combination of noise barriers and tall trees led to enhanced mixing and pollutant dispersion, leading to lower downwind pollutant concentrations. Trees and other vegetation may also reduce pollutant concentrations by enhancing deposition of certain pollutants (Beckett et al., 2000; Bussotti et al., 1995; Heath et al., 1999; Heichel and Hankin, 1976; Munch, 1993).

Our research characterized the influence of structures on the dispersion and transport of traffic-generated emissions in the near road microenvironment. The primary objectives of the study were to identify appropriate monitoring techniques to measure the complex mixture of traffic-related pollutants in the near road microenvironment; however, the study location also provided an opportunity to evaluate the effects of roadside barriers on near road air quality.

METHODOLOGY

The study design focused on highly time-resolved characterization of traffic activity, meteorology, and air quality at varying distances from the road as described by Baldauf et al. (2007). A site in Raleigh, North Carolina provided the opportunity to compare air quality near a highway with and without noise barriers. The site also contained an open field and a residential neighborhood with mature vegetation. Figure 1 shows the project location, adjacent to U.S. Interstate 440 (I-440), a limited access highway supporting approximately 125,000 vehicles per day. An access road runs parallel to the highway, approximately 10 m from the nearest travel lane. An open field at-grade with the highway extends for approximately 120 m to the north of I-440, with the only structures present between the field and I-440 travel lanes a guardrail and shrubbery approximately 1 m in height and width between the guardrail and the access road. A noise barrier approximately 6 m in height and 5 m from the edge of the I-440 travel lanes began approximately 40 m west of the center of the open field and extends over 1 km west along I-440. South of the highway, an approximately 5 m elevation drop exists at a 45-degree angle. Two-story office buildings are located at the bottom of the hill; thus, the rooftops of these buildings are essentially at-grade with the highway. With the exception of the highway, no other major air pollution sources were identified within a 5 km radius of the study site. For this site, a wind direction of 206 degrees represented winds blowing normally from the road.

The monitoring network consisted of two transects of fixed site monitors: one to assess near-road air quality with no obstructions to air flow present and another with a noise barrier adjacent to the road. The open field transect consisted of monitors placed in a field approximately 50 m east of the beginning of the noise barrier. The behind-barrier transect consisted of monitors placed along a lightly traveled residential road approximately 50 m west of the beginning of the noise barrier. The downwind air quality sites used to assess roadside barrier effects were located perpendicular to I-440 approximately 20, 50, 100 and 300 m to the north of the edge of the nearest travel lane. Data collection occurred during July and August, 2006.

Meteorological measurements included wind speed, wind direction, temperature, and humidity. Sonic anemometers were located at downwind sites of 5, 20, and 100 m from I-440, while cup anemometer stations were located 20 and 300 m from the highway along the open field transect. Comparison of the data at the 5 and 20 m sites provided information on the horizontal and vertical extent of the turbulent mixing zone from the highway. The wind sensors at the 100 and 300 m sites provided data on the consistency of winds from the road, as well as the potential influence of the building on air flow at these monitoring sites. For the study site configuration, a wind direction of 206 degrees (from true north) signifies winds blowing normal from the road to the monitoring sites. For subsequent analyses, the term winds directionally from the road describes winds from vectors of 161-251 degrees (from true north) unless otherwise noted.

Video surveillance equipment monitored traffic activity on I-440 as well as the access road parallel to the highway. Video recordings were collected during daylight hours, with traffic volume, speeds, and fleet mix identified for 20 s time intervals. Air quality monitors measured pollutant concentrations at varying distances from the road, as shown in Figure 1. An on-site master clock provided time-synchronized measurements for all monitoring equipment.

Select monitoring equipment was used to compare air quality measurements near the road with and without noise barriers and vegetation. CO measurements were collected using optical remote sensing (ORS) devices adjacent to the road along the open field and behind the noise barrier. One open-path Fourier transform infrared (OP-FTIR) unit (Industrial Monitoring Control Corporation (IMACC), Round Rock, Texas, USA) was located adjacent to the road, with a second OP-FTIR (Midac Corporation, Costa Mesa, CA, USA) located behind the noise barrier. All spectrometers were monostatic in configuration and measured CO with 30 s time resolution. The optical path adjacent to the road was 149 m, and the optical path behind the noise barrier was 129 m. The height of these optical paths was approximately 2 m above the ground to approximate breathing-level height.

Portable industrial hygiene monitors (P-Trak Model 8525, TSI Inc., Shoreview, MN, USA) continuously measured total particle number counts at all of the monitoring sites to assess changes in counts along the transects with and without noise barriers. These samplers operated 12 hr per day (5:30 am to 5:30 pm) and collected 20 s average particle number data. These samplers required the addition of alcohol to the monitors' wick after six hours of sampling. Alcohol changes occurred at 8:30 am and 2:30 pm daily. Study personnel rotated these monitors among the study sites every third day of sampling.

In addition to the fixed site monitoring, the Duke University mobile laboratory provided PM size distribution data at varying locations throughout the study area. A van equipped with global positioning system (GPS) and PM measurement devices recorded the location and pollutant concentrations while driving over a predefined route in the vicinity of the fixed sites as shown in Figure 1. This route allowed for measurements parallel to I-440 with and without a noise barrier present. The route also allowed for perpendicular transects away from the road with no obstructions (approximately 200 meters east of the barrier end), with only a noise barrier (approximately 50 m west of the barrier end), and with a barrier and vegetation (approximately 300 m west of the barrier end).

Inlet air entered the van's sampler through a 3 m long, 0.5 in outer diameter stainless steel pipe, with the inlet located at a 2 m height, above and in front of the driver's side of the van. Instrument clocks and the GPS were synchronized before each sampling period. The data were adjusted for the delay time required for air to reach the instruments through the sampling line.

Khylstov et al. (2004, 2006) provide more detail on the mobile monitoring system used in the study.

The data from the on-board instruments were combined with the location data from the GPS to produce a concentration map of the study area. The resolution of the GPS limits the spatial resolution of the measurements to approximately 7 m. Two identical Differential Mobility Analyzer-Condensation Particle Counter (3071 DMA and 3010 CPC, TSI Inc., Shoreview, MN, USA) combinations provided number concentrations of 20 and 75 nm size particles. One DMA was set to a constant voltage, selecting a nearly monodisperse aerosol of 20 nm in diameter. The other DMA was set to select 75 nm particles at ten measurements per second (10 Hz). The particle counts were converted to the number concentration using the charging efficiency for the particles at that size. To obtain information on other particle sizes, and to assess how the variability at one size compares to the variability at other sizes, a limited set of runs were made over the same route. One instrument sampled 20 nm particles at 10 Hz, while the other collected in the Scanning Mobility Particle Sizer (SMPS) mode (Wang and Flagan, 1990) measuring the size distribution in the range of 12 to 300 nm with an averaging period of 20 s.

RESULTS AND DISCUSSION

The results from the measurements collected comparing air quality concentrations with no barriers, a noise barrier only, and a noise barrier and vegetation indicated that the barriers impacted the transport and dispersion of air contaminants in the near-road microenvironment. Time series CO measurements from the two ORS systems approximately 10 m from I-440 along the open field and behind the barrier highlighted the impact of the noise barrier during changing meteorological conditions. Figure 2 shows the CO measurements, along with the wind direction experienced at the site, for a specific day of the study. The results depicted in this figure were similar for other days as well. Time periods with winds directionally from the road resulted in up to 50 percent lower concentrations behind the barrier; however, winds directionally toward the road led to higher concentrations behind the barrier than in the open field. During the latter conditions, pollutants became trapped behind the barrier. This situation resulted in elevated concentrations on the upwind side of the barrier, although overall concentrations were still lower than when winds came from the road. These results illustrate that noise barriers can trap pollutants on the upwind side, leading to elevated on-road pollutant concentrations when winds blow from the road because the barriers restrict air flow away from the pollutant source.

Figure 3 shows the ratio of the open field to behind barrier PM number concentration measurements from the P-trak units at the 20-meter downwind fixed sites. These data represent 15-minute average concentrations when the winds were directionally from the road (161 – 251 degrees). Time periods with a large number of vehicles on the access road were removed to minimize the influence of vehicle emissions behind the barrier for this comparison. Results demonstrated the variability of barrier effects on proximal pollutant concentrations. Reductions up to 50 percent occurred behind the barrier, with the average reduction approximately 20 percent during the study. However, Figure 3 revealed a few instances when higher concentrations existed behind the barrier than in the open terrain situation, even with winds from the road. Time of day, ambient PM number concentrations, and wind speeds did not influence these results. Since traffic activity on the residential road along the "behind barrier" transect could not be monitored during this study, we speculate that vehicle operations along this road may have contributed to these results.

Mobile monitoring data also allowed a comparison of PM number concentrations from the DMA-CPC units along the open field and behind the noise barrier while driving along the access road parallel to I-440. Figure 4 shows 20 and 75 nm particle number concentrations measured approximately 15 meters from the nearest travel lane of I-440 during time periods with winds directionally from the road. These results also indicate that noise barriers can reduce pollutant concentrations in close proximity to the road, with average concentrations approximately 30 percent lower behind the barrier with winds from the road. This figure also suggests that some pollutants were swept around the end of the barrier as significant decreases in pollutant concentrations did not occur until approximately 40 meters west of the barrier end. In addition, the figure also indicates that concentrations continued to decrease with increasing distance from the end of the barrier. Thus, a continuous stretch of barrier may result in greater pollutant concentration reductions. Figure 4 suggests that these reductions may be as great as 50 percent with winds directionally from the road.

In addition to affecting air quality in close proximity to the road, barriers may influence pollutant concentrations at greater distances away from the road. Figure 5 shows the average PM number concentrations measured by the P-traks along the open field and noise barrier only transects during the study with winds perpendicular ($\pm$45 degrees) from the road. These data were normalized by the average concentrations measured at the upwind monitoring site. The data indicated that the average concentrations behind the barrier were lower than concentrations at an equivalent distance from the road without any barrier. This figure shows that the barrier reduced average concentrations by 15 to 25 percent within the first 50 m of the road, with concentrations becoming equivalent approximately 150 to 200 m from the road. Since the "behind barrier" transect was located 50 m from the end of the noise barrier, these equivalent concentration measurements may have occurred at a shorter distance from the barrier for this field study than under conditions of a continuous barrier section. In addition, although the concentrations behind the barrier were generally lower than the open field concentrations, both measurements were higher than the upwind average concentration. Figure 5 also showed increased PM number concentrations behind the barrier when comparing the 300-m sites; however, these differences were not significant.

Mobile monitoring data using the DMA-CPC units allowed a further evaluation of PM number concentrations for three scenarios: no barriers, noise barrier only, and a noise barrier with surrounding vegetation. Figure 6 results also indicated that the presence of a noise barrier generally reduced particle number concentrations. The results in Figure 6 showed larger reductions of the smaller, 20 nm particles than for the larger 75 nm particle size. For the 20 nm particles, equivalent average concentrations in the open terrain and behind the barrier occurred approximately 120 meters from the road, a distance consistent with the results shown in Figure 5. However, the larger, 75 nm diameter particle number concentrations became equivalent only 50 meters from the road. Average number concentrations for the 75 nm particle size actually increased behind the barrier between 70 and 100 m from the road. A review of the 95 percent confidence intervals for the forty mobile measurements collected at each point in the graph revealed higher variability for measurements in the open field and behind the barrier. Data points outside this confidence interval were removed as outliers. Two data points removed included high concentration measurements approximately 300 m from the road behind the barrier. These elevated concentrations were likely attributed to vehicle operations around the facility's parking lot or on the nearby residential road. These events may have also contributed to the elevated concentrations seen in Figure 5 at this distance.

The results in Figure 6 also indicated that the transect with a noise barrier and mature vegetation (trees generally greater than 10 m in height with leaves) resulted in the lowest pollutant concentrations for both particle sizes. Some of the lower concentrations may be a factor of the distance of this transect from the end of the noise barrier (approximately 300 m); however, the presence of vegetation in addition to the noise barrier likely increased turbulence and mixing to further reduce pollutant concentrations. In addition, this vegetation may have provided a filtering effect as described in previous studies, although the isolated effect of vegetation on near road air quality could not be determined in this study. As shown in Figure 6, the reductions from the noise barrier and vegetation appeared to continue more than 300 m from the road, and had the lowest variability among the three transect measurements.

SUMMARY

This paper summarized the results from a study in Raleigh, North Carolina, exploring the effects of a noise barrier on local-scale air quality. The results indicated that this structure reduced pollutant concentrations under certain meteorological conditions. With winds directionally from the road, concentrations of CO and PM number generally decreased between 15 and 50 percent behind the noise barrier. However, pollutants may have been swept behind the end of the barrier during some meteorological conditions that could have resulted in smaller reductions than would have occurred with a more continuous barrier section. In addition, conditions did occur when pollutant concentrations were greater behind a barrier than when no barrier was present. These results also highlight situations when the presence of a noise barrier can lead to higher pollutant concentrations on the road. For PM number concentrations, the presence of mature trees in addition to the barrier resulted in consistently lower pollutant concentrations. Overall, the study results indicated that roadside barriers influenced air flow and pollutant concentrations near the road, but these effects were complex. Further research is needed on the impacts of differing barrier and roadway configurations, as well as the impact of vegetation with and without noise barriers on near-road pollutant concentrations.

ACKNOWLEDGMENTS

This work reflects the collaboration of many individuals working with the EPA near road program. In particular, the authors thank Dan Costa, Doug McKinney, Dave Kryak and Bill Russo of EPA for their assistance in identifying, organizing, and implementing the near road research program. We also want to thank the North Carolina Lions Club for the Blind for access to portions of the field site used in this study.

DISCLAIMER

The research presented here was performed under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number DW13921548. This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views. U. S. Government right to retain a non-exclusive royalty-free license in and to any copyright is acknowledged.

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Figure 1. Map of the study location including the relative placement of the fixed site monitoring instrumentation, shown as yellow circles, and a route driven by a mobile monitoring vehicle in light blue.

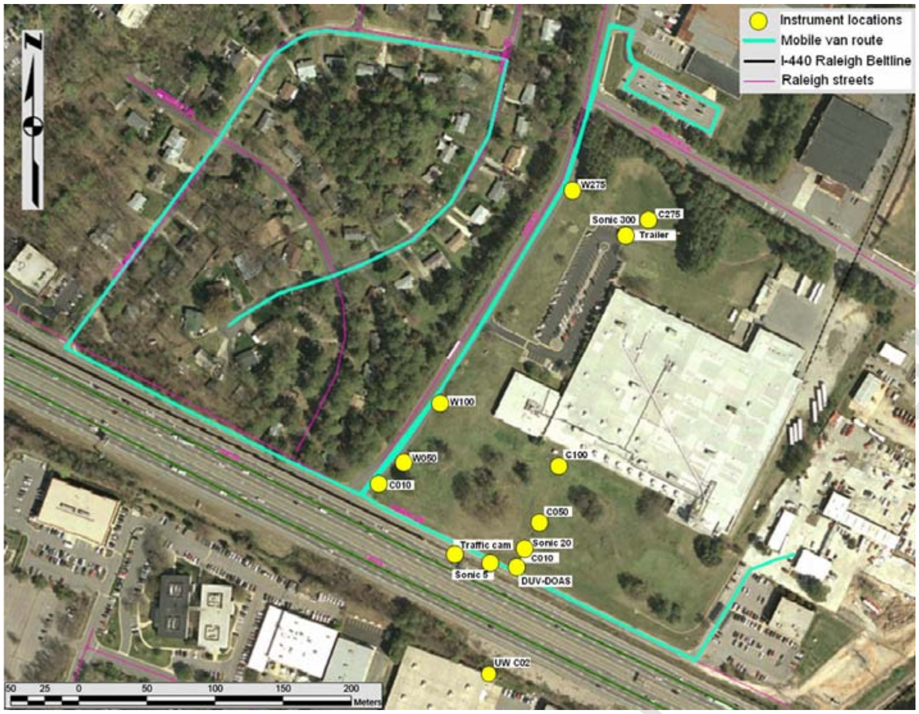


Figure 2. Comparison of CO time series measurements from ORS at an open field and behind a noise barrier. Measurements were taken 10 meters from the road on August 3, 2006. A wind direction of 206 degrees represents winds normal from the road.

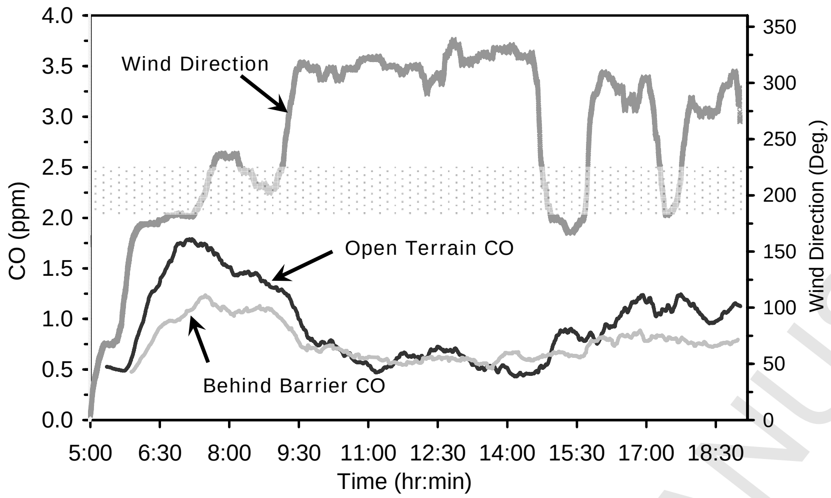


Figure 3. Ratio of open field to behind barrier PM number concentrations measured with the P-trak units at the 20-meter downwind sites under wind directions generally from the road (206 degrees represents winds normal from the road).

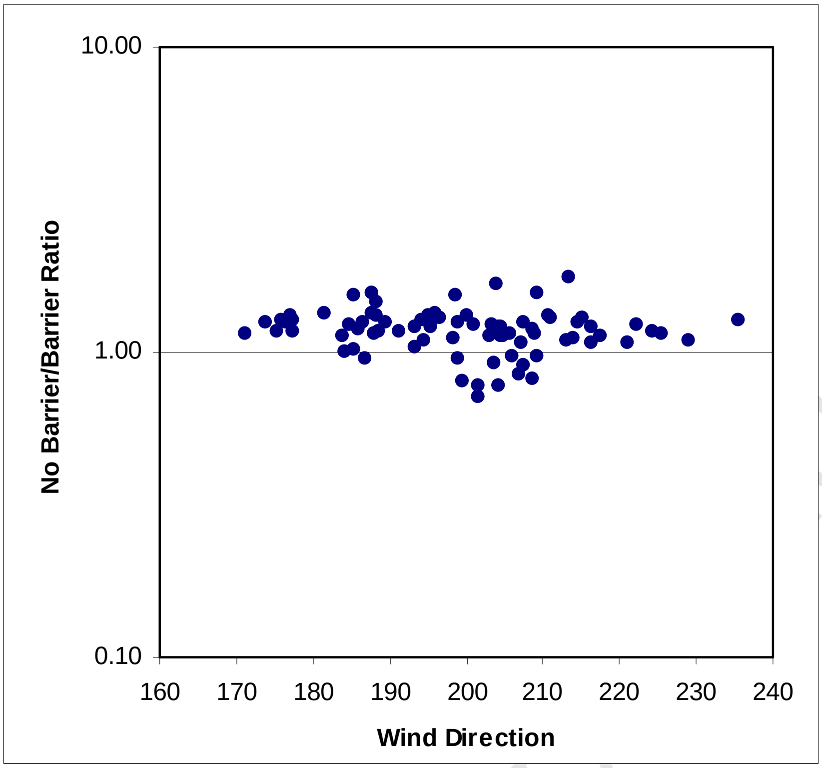
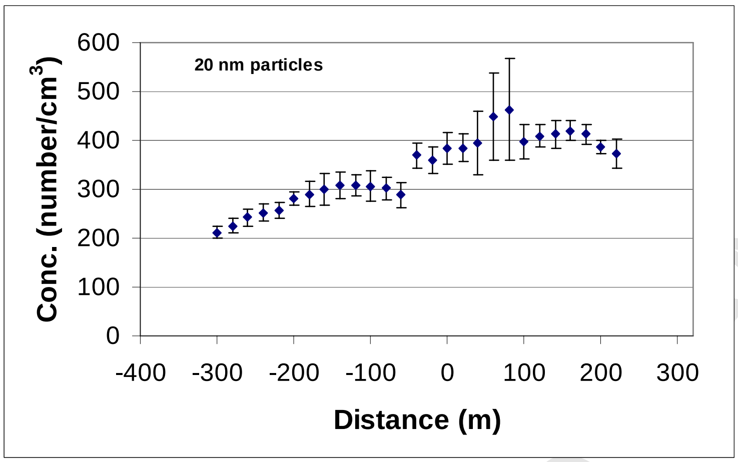


Figure 4. Comparison of 20 nm and 75 nm particle number concentrations measured with the DMA-CPC units parallel to the highway 15 meters from the nearest travel lane. Each data point represents the average and 95% confidence interval of approximately 40 measurements taken at that location with winds directionally from the road. The origin indicates the beginning of the noise barrier with negative x-value measurements taken behind the barrier.

a) 20 nm measurements



b) 75 nm measurements

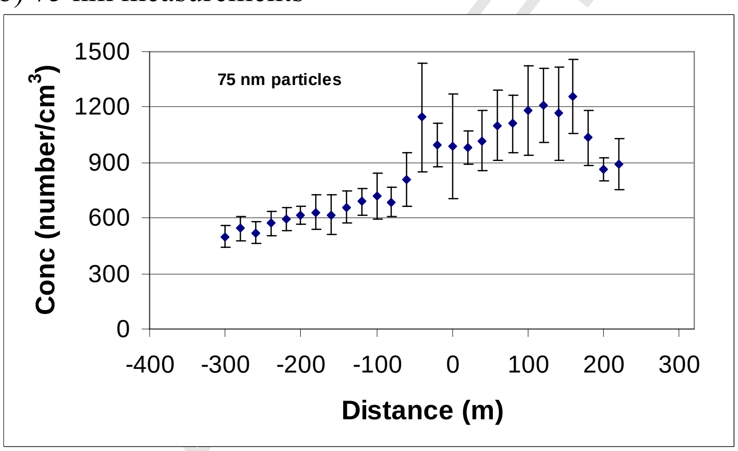


Figure 5. Average PM number concentrations measured by the P-trak units along the open field and behind barrier transects normalized to the upwind measurement.

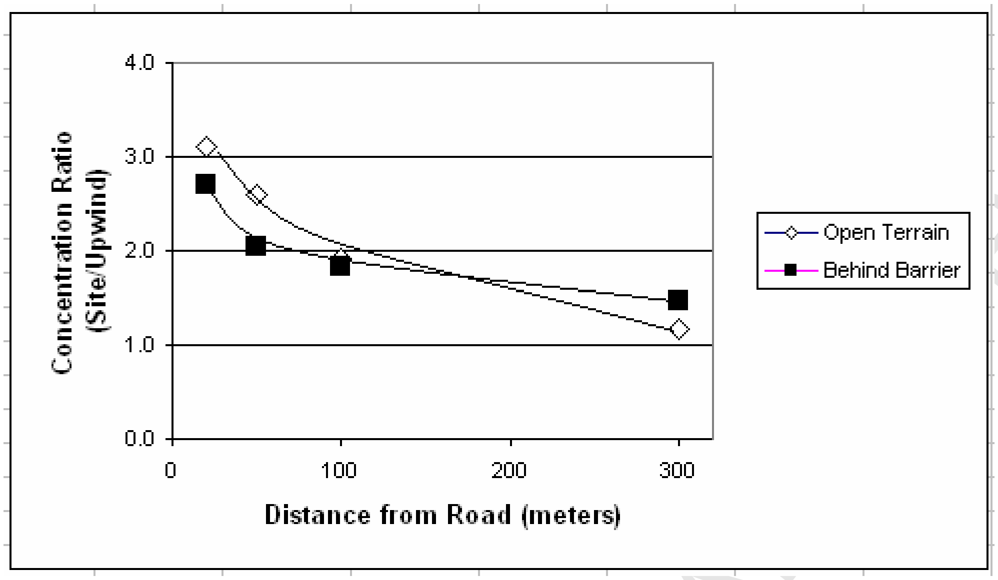
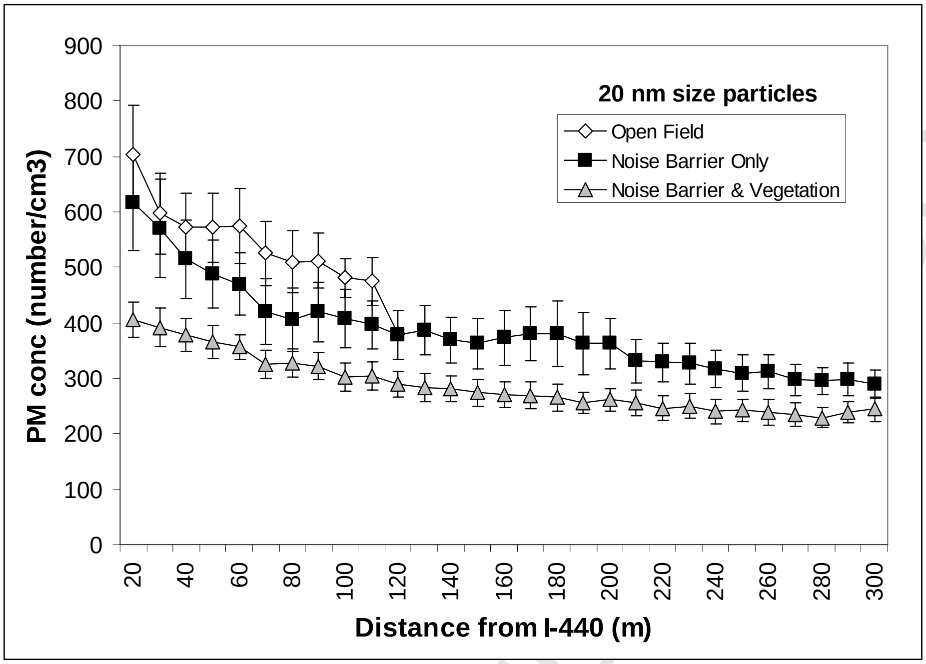


Figure 6. Mobile monitoring measurements of a) 20 nm and b) 75 nm size particles using the DMA-CPC units at varying distances from the road for open terrain, behind a noise barrier only, and behind a noise barrier with vegetation. Bars represent 95 percent confidence intervals for each distance.

a) 20 nm



b) 75 nm